Enhanced Spatial Mapping Capabilities for the Kilo Nalu Observatory

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LONG-TERM GOALS

The Kilo Nalu Observatory, online since October, 2004, provides a window into the Hawaiian coastal environment. Baseline observations at Kilo Nalu include time series of currents, directional waves, temperature profiles and water chemistry at 10m and 20m depths. A high resolution spatial view of local environment is critical in establishing context for the time-series data. This spatial data is being provided via surveys using a REMUS autonomous underwater vehicle (AUV) in conjunction with ROV-based observations. The long-term objectives for the work are to maintain operational AUV support for ONR funded research at Kilo Nalu focusing on nearshore hydrodynamics and sediment transport and to develop new applications using AUV based sampling.

OBJECTIVES

The project builds on existing Kilo Nalu capabilities and expertise with a focus on the following specific objectives:

1. Enhancement of AUV/ROV spatial survey capabilities in support of research at Kilo Nalu
2. Development of data analysis methodology for AUV/ROV data and of a database from new and existing survey observations.
3. Spatial mapping of roughness and bedform characteristics at Kilo Nalu using enhanced AUV/ROV resources.

New capabilities tie in directly with existing ONR funded resources at UH, leveraging on parallel NSF and NOAA funded projects. The project will enable us to maximize potential of regular AUV/ROV surveys at Kilo Nalu.

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APPROACH

The work entails development, analysis and observational phases to address the objectives described above. At present we are completing the development phase with work focusing on initial observations and analysis. The UH REMUS vehicle has been upgraded using project resources along with institutional support, to add a modular nosecone, GPS and WiFi capabilities, digital acoustic modem communications, and new instrumentation for measurement of optical water properties (backscatter, fluorescence). In addition, a narrow beam altimeter has been added to the vehicle to enable roughness measurements.

A significant part of the work is focusing on development of analysis methodology that will extract water property, bed morphology and roughness data from AUV data. Combined with Kilo Nalu time series data, this data will enable, for example, rigorous interpretation of nearshore hydrodynamics and bed morphology as well as for new applications including bedform classification, target identification, water quality assessment and plume dynamics.

The project is providing partial support for a marine research analyst, Jennifer Patterson , who will participate in AUV surveys and development of analysis methodology. A postdoctoral researcher, Sergio Jaramillo, has been supported by the project, focusing on research applications including roughness mapping and AUV data analysis.

WORK COMPLETED

The upgrades to the REMUS AUV were completed in 2008, with pilot surveys carried out offshore of the Ala Wai Canal entrance located 2 km east of Kilo Nalu. In 2009, numerous AUV surveys of the south shore region between the Ala Wai Canal entrance and Kilo Nalu have been carried out as part of the Hawaii Ocean Observing System (HIOOS). Data from these have been used to develop surface maps of temperature, salinity and optical backscatter (http://www.soest.hawaii.edu/OE/KiloNalu/AUV/RemusMissionList.htm), in which the freshwater plume from the Ala Wai can be identified. Additional surveys have been carried out in to characterize ADCP performance and to collect sidescan data in support of ONR funded mine-burial observations (PI Wilkens).

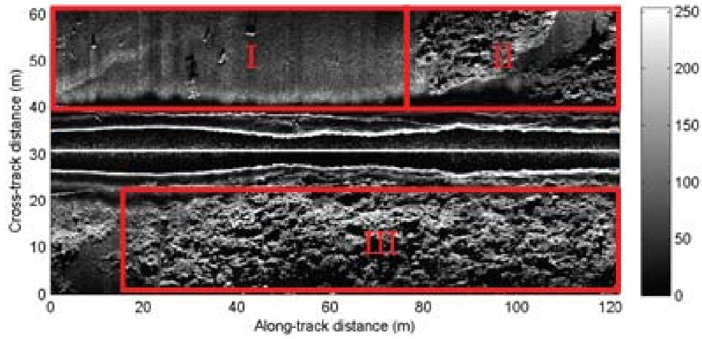
RESULTS

i) Sidescan Roughness

We have carried out analysis of sidescan sonar data with the objective of characterizing roughness over reefs. Nunes and Pawlak (2008) compared sidescan data with vessel and diver-based roughness measurements using a visual characterization of roughness from sidescan imagery. We have been exploring the use of spectral and statistical tools to provide quantitative comparisons of sidescan images with roughness and to enable identification of distinct substrates in the highly heterogenous reef environment. The overarching objective for the work is to relate measureable roughness scales to hydrodynamic roughness and ultimately to drag and dissipation for wave and current flow over highly inhomogeneous boundaries. The variation in spectral content for varying substrate is illustrated in figure 1 using sidescan acoustic intensity data for a sample sidescan image. The image is divided into 3 regions identified as sand (I), coral/sand mix (II) and coral (III) and along-track spectral content is

calculated and shown in figure 1b. It is clear that the spectral energy and slope vary between the regions as is expected from the visual roughness, showing a maximum for the coral bed.

a)



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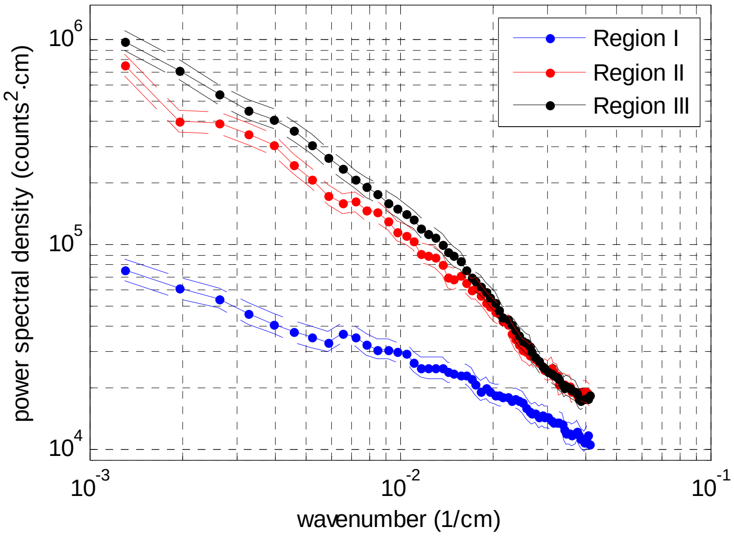


Figure 1 – a) Sample AUV sidescan image from survey at KN with 3 regions identified, corresponding to I: sand, II: mixed sand/coral, III: coral. b) acoustic intensity power spectral density from 3 regions identified in (a).

It can be expected that the phase (in addition to amplitude) of roughness wavelengths will also influence drag. Conceptually, it is clear that a boundary where a spectral distribution of roughness scales is organized will have different drag from one in which components are distributed randomly. Some statistical measure of this can be obtained from higher order spectral moments (skewness, excess kurtosis). As illustrated in figure 2 for the sidescan data from figure 1a, these quantities vary significantly with substrate type.

We have also been exploring statistical representation of roughness phase using entropy spectra. The entropy can be calculated as a function of L across each image using principle component analysis of subimages of length, L. For a single colored image, the entropy is null. For fully random roughness, probabilities will tend to a uniform distribution and the entropy will increase monotonically with the number of features. The entropy, then, gives a measure of the roughness complexity, between a featureless bed to random roughness, as a function of the length scales L/n. Figure 7 includes an

example of this type of analysis, carried out in one dimension for the image in figure 6a, at a single length scale, *L*.

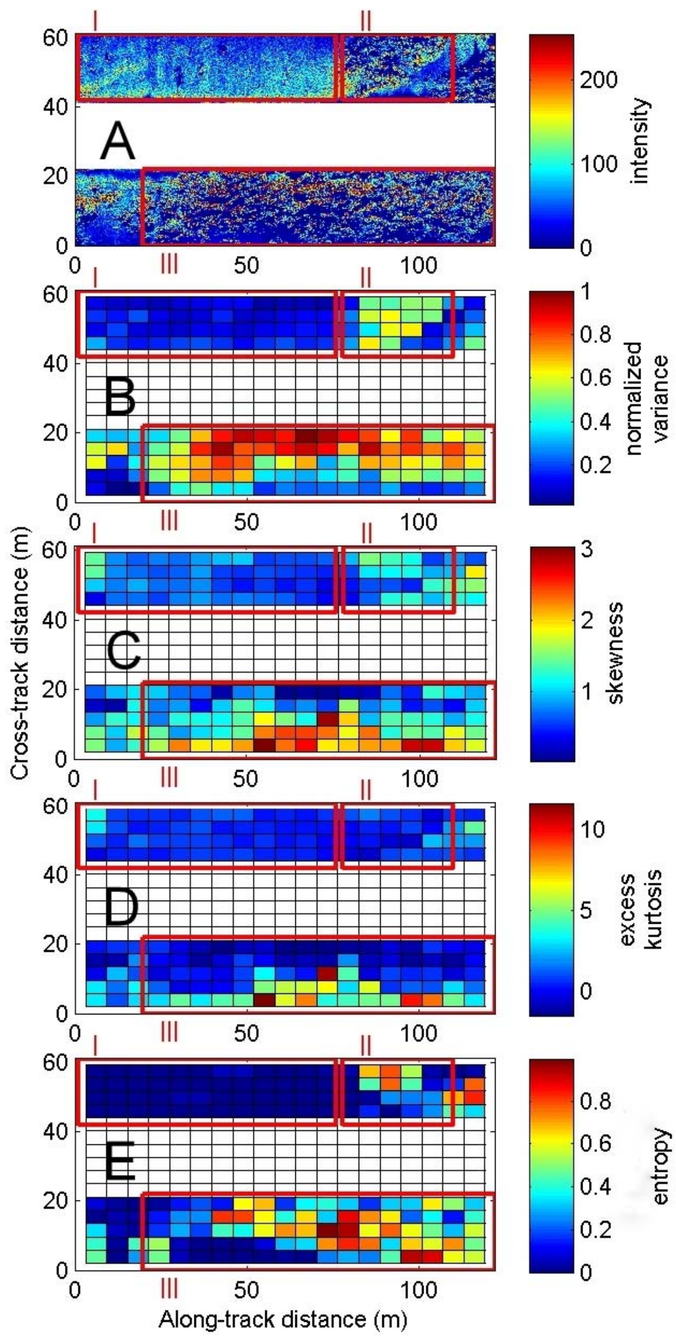
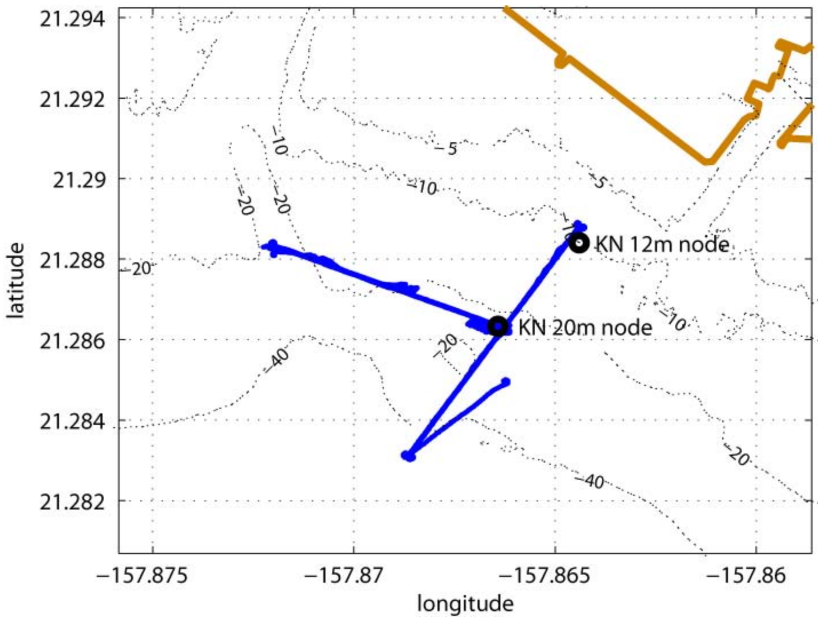


Figure 2 – Statistical analysis of sidescan image from figure 6. Panels show (as labeled): intensity, variance, skewness, kurtosis and entropy (respectively). Regions I, II and II correspond to sand, sand/coral and coral as identified in figure 6.

Though interpretation of sidescan images is complicated by the presence of shadows for highly rugose boundaries like coral reefs, this analysis indicates that statistical tools can be effective in identifying variable substrates and can provide guidance on bed roughness characteristics. In addition to enabling substrate identification and roughness characterization, sidescan data also provides the opportunity to examine the 2D structure of the bed.



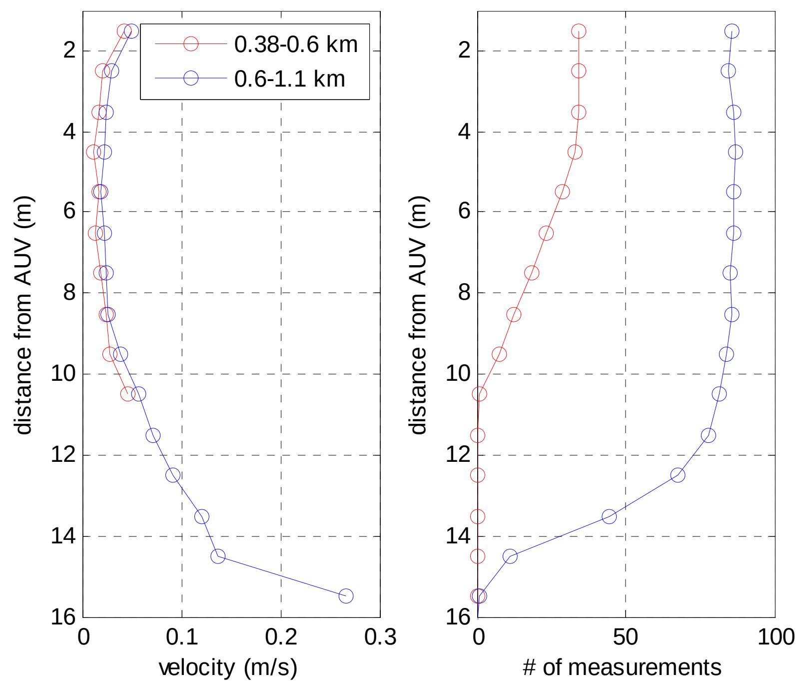


Figure 3 – Top: Survey tracks from AUV DVL test mission, including locations of Kilo Nalu 12 and 20m nodes. Bottom, left: Mean difference between the shoreward and seaward along-track velocities measured by the AUV during the cross-shore survey legs for nearshore (red) and offshore (blue) portion. Bottom, right: number of measurements included in averages.

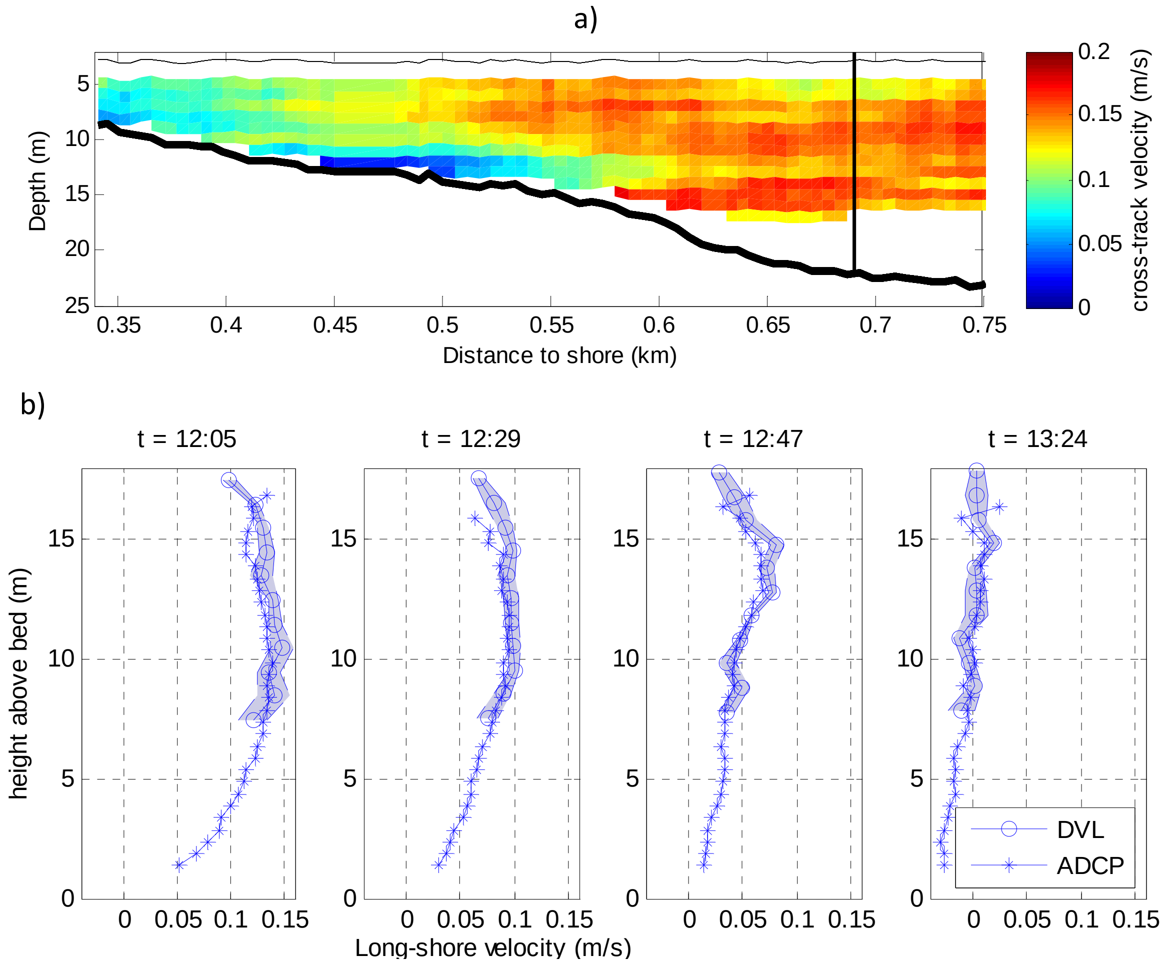


Figure 4 – AUV-based current profiling. a) Cross-shore section of along-shore velocity from AUV cruising at 3m depth. Vertical line indicates location of Kilo Nalu 23m ADCP. b) Comparison of velocity profiles from AUV DVL (100m average) with Kilo Nalu 23m ADCP (50s average). Error bands represent one standard deviation of DVL data including both instrument error and spatial variability.

ii) DVL Velocity Bias

Performance of the AUV's Doppler velocity log (DVL) has been assessed via comparisons with fixed point ADCPs. Observations by Fong and Jones (2006) on a REMUS DVL indicated that the measured water column velocity profiles were subject to a weak bias in the direction of vehicle motion particularly for low backscatter environments. The reasons for the observed bias remain unclear. It has been suggested that the observed bias could be caused by ADCP 'ringing' (Fong and Monismith, 2004), but this possibility has not yet been thoroughly addressed. Another possible source for the bias is error related to bottom tracking and beam geometry. Fong and Monismith (2004) ruled out bottom track errors for shipboard ADCP measurements, but error sources have not been examined for AUV mounted ADCP's. Figure 3 shows survey tracks from a REMUS mission designed to characterize

DVL bias. The vehicle followed a constant depth track for along- and across-shore legs which passed over fixed ADCPs at the Kilo Nalu Observatory's 12 and 20m node sites. A clear bias in the along-track direction was observed (figure 3) with a characteristic vertical structure. Observations show that cross-track velocities are not affected, however. Further analysis is exploring the variation of the bias with ADCP settings and vehicle velocity.

iii) AUV-based Current Profiling

Comparisons of DVL data with KN fixed ADCPs indicate that the REMUS ADCP can be effective in resolving steady BL structure with spatial averaging of 50-100m. Figure 5 shows data from a REMUS survey at Kilo Nalu illustrating the ability of the vehicle for water column velocity profiling. The REMUS AUV was set to run 8 cross-shore transects (16 legs) between the Kilo Nalu 12m and 20m nodes (ADCPs at 12 and 23m, approximately located at 0.39 and 0.69 km from shore in the figure). Figure 5a shows alongshore velocity contours from one of the legs. The data has been filtered spatially over 100m (50s) to eliminate surface wave biases. Significant spatial variability is observed in the steady alongshore and cross-shore (the latter not shown) currents. In Figure 5b, the DVL data is compared with measurements from the 23m Kilo Nalu bottom-mounted ADCP. DVL data is averaged over 100m in the cross-shore direction (centered at the ADCP location), with the fixed ADCP velocities averaged for the corresponding time (approximately 50s). Both instruments capture the temporal variation and vertical structure in the current. While some portion of the scatter in the DVL data can be attributed to instrument error (the fixed ADCP used a high resolution sampling mode with lower single ping error), the data in figure 5a suggests that much of the scatter is associated with real spatial variability.

IMPACT/APPLICATIONS

The work described above has enabled new research applications focusing on benthic roughness mapping and classification which have implications for nearshore wave and current modeling. Combined with direct measurements of roughness from a narrow-beam altimeter recently added to the UH AUV, sidescan imagery can provide valuable 2D context, enabling substrate identification and classification in complex reef environments. These observations can potentially be correlated with remote sensing methods to provide more benthic classification with more extensive spatial coverage.

The detailed analysis of AUV DVL performance, underway as part of the ongoing work, is critical for development of AUV-based spatial hydrodynamic sampling. AUV spatial surveys can, in turn, provide a key tool for assessment and characterization of nearshore processes on complex coastlines.

RELATED PROJECTS

The work discussed here is being carried out in parallel with a complementary project funded by NOAA Coastal Services Center targeting the development of the Hawaii Ocean Observing System (HIOOS). REMUS AUV surveys are a key component of HIOOS water quality efforts which include support for regular surveys of the south shore, along with 'event' based surveys that focus on observation of freshwater fluxes into the coastal zone, associated with rainfall events. HIOOS has been providing partial support for a technician to carry out the surveys and associated data analysis.

Project resources have also contributed to other ONR work including observations of mine burial (N00014-07-1-0601: A Mine Burial Expert System Field Test, PI: Wilkens) and nearshore wave and

current dynamics (N00014-06-1-0224: Effects of Offshore Forcing in the Nearshore Environment, PIs Pawlak and Merrifield).

The work here is also closely integrated with an NSF project, funded under the Coastal Ocean Processes (CoOP) program since 2005. The NSF work has funded an expansion of the Kilo Nalu Observatory including new baseline infrastructure. The work is examining the response of benthic boundary layer geochemical fluxes to physical forcing including surface waves and internal tides. The project has included funding for numerous AUV surveys which have provided a solid foundation for further development of the applications and methods undertaken as part of this work.

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